CHAPTER 3

STORM DRAINAGE SYSTEM

22 February 2000

Chapter Three - Storm Drainage System

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3.1 Overview

3.1.1   Introduction

Every urban area has two separate and distinct drainage systems, whether or not they are actually planned for and designed. One is the *minor* system and the other is the *major* system. To provide for orderly urban growth, reduce costs to taxpayers, and obviate loss of life and property damage, both systems must be planned and properly engineered.

In this chapter, guidelines are given for evaluating and designing storm drainage of the minor system. The minor drainage system is typically thought of as storm drains and related appurtenances, such as inlets, curbs and gutters. The minor system is normally designed for floods with return frequencies of 5-years to 10-years, depending upon the kind of land use. The minor system has also been termed the "convenience" drainage system. If downstream drainage facilities are undersized for the design flow, a detention structure may be needed to reduce the possibility of flooding. Storm sewer systems shall be designed using "City of Lincoln Standard Specifications for Municipal Construction."

3.1.2   Symbols and Definitions

To provide consistency within this chapter as well as throughout this manual, the following symbols will be used. These symbols were selected because of their wide use in storm drainage publications. In some cases the same symbol is used in existing publications for more than one definition. Where this occurs in this chapter, the symbol will be defined where it occurs in the text or equations.

Table 3-1 Symbols, Definitions And Units

Symbol	Definition	Units
a	Gutter depression	in
A	Area of cross section	ft^2
d or D	Depth of gutter flow at the curb line	ft
D	Diameter of pipe	ft
E_o	Ratio of frontal flow to total gutter flow Q_w/Q	-
g	Acceleration due to gravity (32.2 ft/s^2)	ft/s^2
h	Height of curb opening inlet	ft
H	Head loss	ft
K	Loss coefficient	-
L	Length of curb opening inlet	ft
L_T	Length of curb opening inlet required for total interception of gutter flow	
P	Pipe length	ft
n	Roughness coefficient in the modified Manning formula for triangular gutter flow	-
P	Perimeter of grate opening, neglecting bars and side against curb	ft
Q	Rate of discharge in gutter	cfs
Q_i	Intercepted flow	cfs
Q_s	Gutter capacity above the depressed section	cfs
R	Hydraulic radius	ft
S or S_x	Cross slope - Traverse slope	ft/ft
S or S_L	Longitudinal slope of pavement	ft/ft
S_f	Friction slope	ft/ft
S'_w	Depression section slope	ft/ft
T	Top width of water surface (spread on pavement)	ft
T_s	Spread above depressed section	ft
V	Velocity of flow	ft/s
W	Width of depression for curb opening inlets	ft
Z	T/d, reciprocal of the cross slope	-

3.1.3   Concept Definitions

Definitions of concepts important in storm drain analysis and design used in this chapter are presented below.

Bypass

Flow which bypasses an inlet on grade and is carried in the street or channel to the next inlet downgrade. Inlets may be designed to allow a certain amount of bypass for one design storm and larger or smaller amounts for other design storms. The spread for lower catch basins must consider a reasonable calculated bypass flow from upper facilities.

Curb-Opening Inlet

A drainage inlet consisting of an opening in the roadway curb.

Drop Inlet

A drainage inlet with a horizontal or nearly horizontal opening.

Equivalent Cross Slope

An imaginary continuous cross slope having conveyance capacity equal to that of the given compound cross slope.

Flanking Inlets

Inlets placed upstream and on either side of an inlet at the low point in a sag vertical curve. The purpose of these inlets are to intercept debris as the slope decreases and to act in relief of the inlet at the low point.

Frontal Flow

The portion of the flow which passes over the upstream side of a grate.

Grate Inlet

A drainage inlet composed of a grate in a parking lot, alley or area drain. Grated inlets are not allowed in standard roadway sections.

Gutter

That portion of the roadway section adjacent to the curb which is utilized to convey storm runoff water. It may include a portion or all of a traveled lane, shoulder or parking lane, and a limited width adjacent to the curb may be of different materials and have a different cross slope.

Hydraulic Grade Line

The hydraulic grade line is the locus of elevations to which the water would rise in successive piezometer tubes if the tubes were installed along a pipe run.

Inlet Efficiency

The ratio of flow intercepted by an inlet to total flow in the gutter.

Pressure Head

Pressure head is the height of a column of water that would exert a unit pressure equal to the pressure of the water.

Scupper

A vertical hole through a bridge deck for the purpose of deck drainage. Sometimes, a horizontal opening in the curb or barrier is called a scupper.

Side-Flow Interception

Flow which is intercepted along the side of a grate inlet, as opposed to frontal interception.

Slotted Drain Inlet

A drainage inlet composed of a continuous slot built into the top of a pipe which serves to intercept, collect and transport the flow.

Splash-Over

Portion of the frontal flow at a grate which skips or splashes over the grate and is not intercepted.

Spread

The width of flow measured laterally from the roadway curb.

Velocity Head

Velocity head is a quantity proportional to the kinetic energy of flowing water expressed as a height or head of water.

For a more complete discussion of these concepts and others related to storm drain design, the reader is referred to - Drainage of Highway Pavements, Federal Highway Administration, Hydraulic Engineering Circular No. 12, March 1984.

3.2 Pavement Drainage

3.2.1 Introduction

There are many details to consider in the design and specification of storm drain systems. ASCE Manuals of Engineering Practice (1960, 1982, 1983) as well as other trade and vendor publications provide construction and specification details beyond the scope of this text. During the design phase, the system drainage area is defined and preliminary drainage routes are identified based on hydrologic analyses. Integration of the system with environmental features and neighborhood amenities should be assessed, and the location of quantity and quality control structures is determined.

The hydrologic analyses should include defining drainage areas for each inlet or ditch start, developing flow estimates for design frequencies throughout the system, and development of flow and spread calculations to determine permissible maximum spread.

Typical design factors to be considered during gutter, inlet, and pavement drainage calculations include:

- Return period
- Spread
- Storm drain location
- Inlet types and spacing

- Longitudinal slope
- Cross slope
- Curb and gutter sections
- Roadside and median channels

- Bridge decks
- Shoulder
- Median/Median barriers

3.2.2 Return Period

The design storm return period for pavement drainage should be consistent with the frequency selected for other components of the drainage system. The major considerations for selecting a design frequency are roadway classification, roadway speed, hazards, and pedestrian traffic.

3.2.3 Spread

For multi-laned curb and gutter or guttered roadways with no parking, it is not practical to avoid travel lane flooding when grades are flat. Allowable maximum encroachment is provided in the following table.

Table 3-2 Allowable Maximum Encroachment for Minor Storms

Street Classification	Maximum Encroachment
Local	No curb overtopping.
Collector	No curb overtopping.
Arterial	No curb overtopping. Flow spread must leave at least one lane free of water in each direction.
Freeway	Refer to Nebraska Department of Roads design criteria.

When these encroachments are met, the storm drain system shall commence.

For the major storm runoff, the following street inundation is allowable:

Table 3-3 Allowable Maximum Encroachment for Major Storms

Street Classification	Maximum Encroachment
Local and Collector	The depth of water over the gutter flowline shall not exceed the right-of-way width.
Arterial	The depth of water at the street crown shall not exceed 6 inches.
Freeway	Refer to Nebraska Department of Roads design criteria.

Table 3-4 provides recommendation for allowable cross street flow.

Table 3-4 Allowable Cross Street Flow

Street Classification	Minor Storm Design Runoff	Major Storm Design Runoff
Local	Flow equivalent to 5" depth in upstream curb and gutter section	The depth of water over the gutter flowline shall not exceed the right-of-way width.
Collector	Where cross pans allowed, depth of flow shall not exceed 6 inches.	The depth of water over the gutter flowline shall not exceed the right-of-way width.
Arterial	None	6 inches or less over crown.
Freeway	Refer to Nebraska Department of Roads design criteria.	Refer to Nebraska Department of Roads design criteria.

3.2.4 Longitudinal Slope

A minimum longitudinal gradient is important for a curbed pavement, since it is susceptible to stormwater spread. Flat gradients on uncurbed pavements can lead to a spread problem if vegetation is allowed to build up along the pavement edge.

Curb and gutter grades that are equal to pavement slopes shall not exceed 8 percent or fall below 0.5 percent without approval from the Director of Public Works and Utilities.

3.2.5 Cross Slope

Roadway cross slopes are determined by the City of Lincoln standard roadway sections. Drainage from median areas should not cross traveled lanes. Median shoulders should generally be sloped to drain away from the pavement. Narrow, raised medians are not subject to these provisions.

3.2.6 Curb And Gutter

Curb and gutter installation shall be designed in accordance with the most current City Standard Drawings and Specifications.

3.2.7 Roadside And Median Channels

Curbed highway sections are relatively inefficient at conveying water. The area tributary to the gutter section should be kept to a minimum to reduce the hazard from water on the pavement. Where practicable, the flow from major areas draining toward curbed highway pavements should be intercepted by channels and routed away from the highway pavement.

Large median areas and inside shoulders should be sloped to a center swale, preventing drainage from the median area from running across the pavement. This is particularly important for high-speed facilities, and for facilities with more than two lanes of traffic in each direction.

3.2.8 Bridge Decks

Drainage of bridge decks is similar to other curbed roadway sections. It is often less efficient, because cross slopes are flatter, parapets collect large amounts of debris, and small drainage inlets on scuppers have a higher potential for clogging by debris. Because of the difficulties in providing and maintaining adequate deck drainage systems, gutter flow from roadways should be intercepted before it reaches a bridge. In many cases, deck drainage must be carried several spans to the bridge end for disposal.

Storm Drainage System

Scuppers are the recommended method of deck drainage because they can reduce the problems of transporting a relatively large concentration of runoff in an area of generally limited right-of-way. For situations where traffic under the bridge or environmental concerns prevent the use of scuppers, grated bridge drains should be used.

3.2.9   Median/Barriers

Weep holes are often used to prevent ponding of water against barriers (especially on superelevated curves). In order to minimize flow across traveled lanes, it is preferable to collect the water into a subsurface system connected to the main storm drain system.

3.3 Gutter Flow Calculations

3.3.1   General

Gutter flow capacities for City of Lincoln standard street cross-sections are provided in Figure 3-1 for 2.5% pavement cross-slope and in Figure 3-2 for 3.0% pavement cross-slope. For non-standard applications, refer to Sections 3.3.2 through 3.3.7.

3.3.2   Formula

The following form of Manning's Equation should be used to evaluate gutter flow hydraulics:

$$Q = [0.56 / n] \; S_x^{5/3} \; S^{1/2} \; T^{8/3} \tag{3.1}$$

Where: Q = gutter flow rate (cfs)
n = Manning's roughness coefficient
S_x = pavement cross slope (ft/ft)
S = longitudinal slope (ft/ft)
T = width of flow or spread (ft)

3.3.3   Nomograph

A nomograph for solving Equation 3.1 is presented Figure 3-3. Manning's n values for various pavement surfaces are presented in Table 3-2.

Figure 3-1 Gutter Flow Capacity for 2.5% Pavement Cross-Slope

The chart contains the following labels:

- Title: Gutter Flow Capacity, Qp (cfs)
- Subtitle: Based on LSP 640 with 2.5% Cross-slope
- Equation: $Q_g = 0.56 / n \; S_x^{5/3} \; S^{1/2} \; T^{(8/3)}$
- Note: Values Shown are for One-side of Street ONLY
- X-axis: Pavement Slope (S), ft/ft, with values 0.1, 0.01, 0.001
- Y-axis: Gutter Flow (Qg), cfs, with values 100, 10, 1, 0.1
- Curve labels: 5", 4", 3", 2", 1.5", 1"
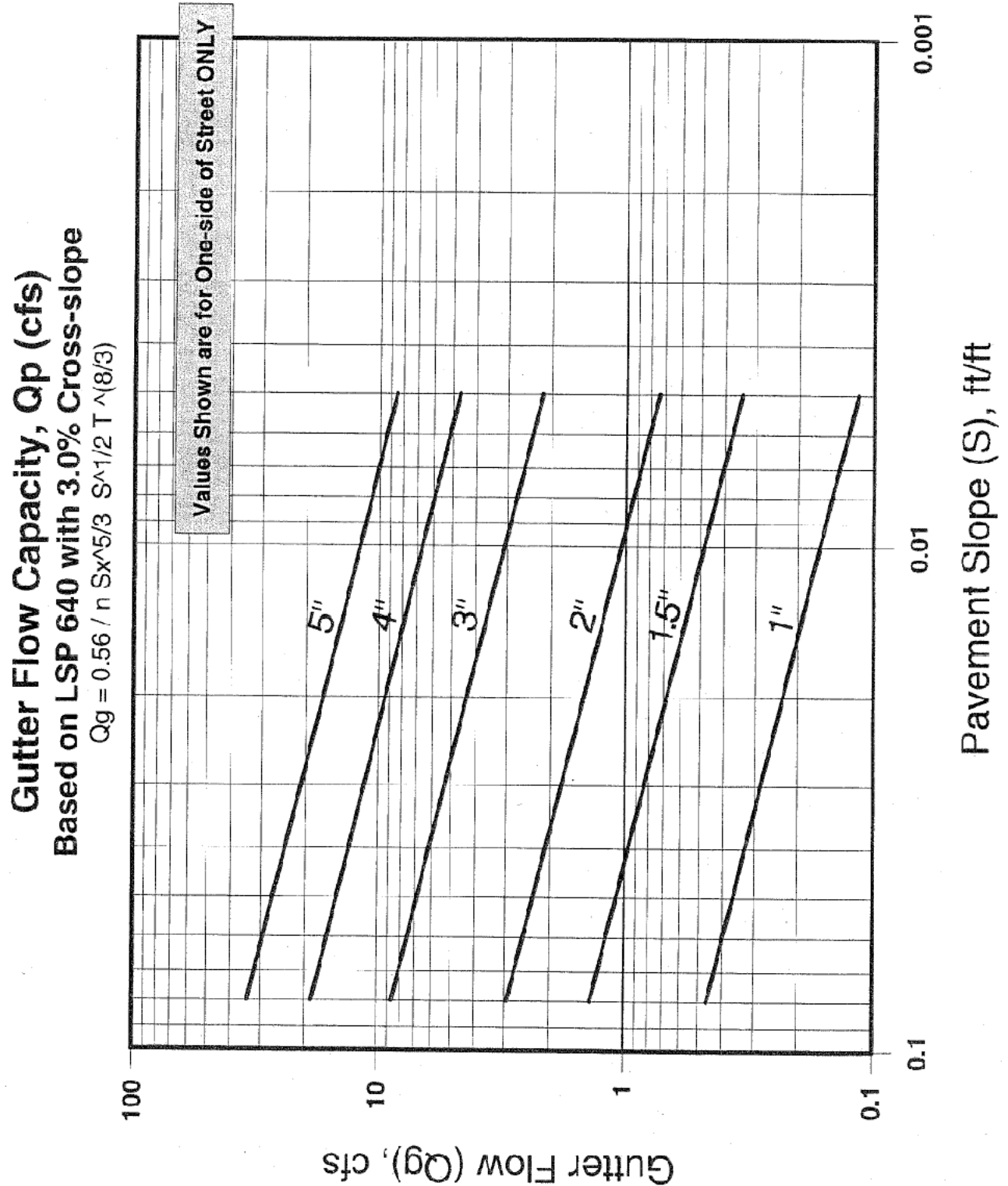
Figure 3-2 Gutter Flow Capacity for 3.0% Pavement Cross-Slope

3.3.4 Manning's n Table

Table 3-2 Manning's n Values For Street And Pavement Gutters

Type of Gutter or Pavement			Range of Manning's n
Concrete gutter, troweled finish			0.012
Asphalt pavement:	Smooth texture		0.013
	Rough texture		0.016
Concrete gutter with asphalt pavement:		Smooth	0.013
		Rough	0.015
Concrete pavement:	Float finish		0.014
	Broom finish		0.016
For gutters with small slopes, where sediment may accumulate, increase above values of n by			0.002

Note: Estimates are by the Federal Highway Administration
Reference: USDOT, FHWA, HDS-3 (1961).

3.3.5 Uniform Cross Slope

The nomograph in Figure 3-3 is used with the following procedures to find gutter capacity for uniform cross slopes:

Condition 1: Find spread, given gutter flow.

1. Determine input parameters, including longitudinal slope (S), cross slope (S_x), gutter flow (Q), and Manning's n.

2. Draw a line between the S and S_x scales and note where it intersects the turning line.

3. Draw a line between the turning line intersection point from Step 2 and the appropriate gutter flow value on the capacity scale. If Manning's n is 0.016, use Q from Step 1 and the right scale on the capacity line. If the Manning's n is not 0.016, multiply Q and n from Step 1 and use the left scale on the capacity scale.

4. Read the value of the spread (T) at the intersection of the line from Step 3 and the spread scale.

$$Q = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67}$$

EXAMPLE: GIVEN:

n=0.016; S_x=0.03

S=0.04 ; T = 6 FT

FIND:

Q =2.4 FT^3/S

Qn = 0.038 FT^3/S

1) For V-Shape, use the nomograph with
$S_x = S_{x1} S_{x2} /(S_{x1} + S_{x2})$

2) To determine discharge in gutter with composite cross slopes, find Q_s using T_s and S_x. Then, use   . to find E_o. The total discharge is $Q = Q_s /(1 - E_o)$, and $Q_w = Q - Q_s$.
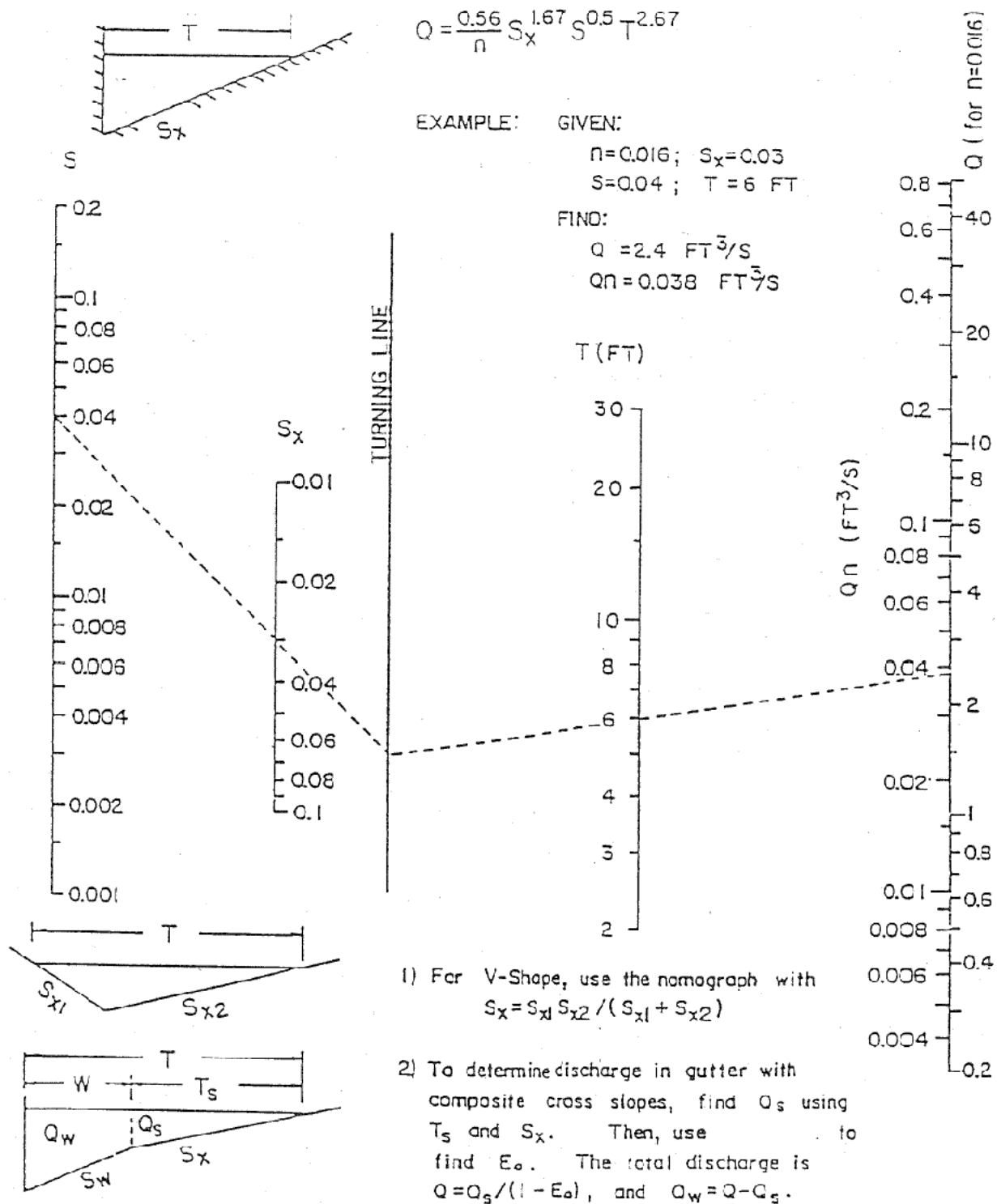
Figure 3-3 Flow In Triangular Gutter Sections

Source: AASHTO Model Drainage Manual, 1991

<u>Condition 2</u>: Find gutter flow, given spread.

1. Determine input parameters, including longitudinal slope(S), cross slope(S_x), spread(T), and Manning's n.

2. Draw a line between the S and S_x scales and note where it intersects the turning line.

3. Draw a line between the turning line intersection point from Step 2 and the appropriate value on the T scale. Read the value of Q (from the right side of the scale) or Qn (from the left side of the scale) from the intersection of that line on the capacity scale.

4. For Manning's n values of 0.016, the gutter capacity (Q) from Step 3 is selected. For other Manning's n values, the gutter capacity times Manning's n (Qn) is selected from Step 3 and divided by the appropriate n value to give the gutter capacity.

3.3.6   Composite Gutter Sections

Figure 3-4 in combination with Figure 3-3 can be used to find the flow in a gutter with width (W) less than the total spread (T). Such calculations are generally used for evaluating composite gutter sections. Figure 3-4 provides a direct solution of gutter flow in a composite gutter section. The flow rate at a given spread or the spread at a known flow rate can be found from this figure. Typical of graphical solutions, extreme care in using the figure is necessary to obtain accurate results.

<u>Condition 1</u>: Find spread, given gutter flow.

1. Determine input parameters, including longitudinal slope (S), cross slope (S_x), depressed section slope (S_w), depressed section width (W), Manning's n, gutter flow (Q), and a trial value of the gutter capacity above the depressed section (Q_s).

2. Calculate the gutter flow in W (Q_w), using the equation:

$$Q_w = Q - Q_s \tag{3.2}$$

3. Calculate the ratios Q_w/Q or E_o and S_w/S_x and use Figure 3-4 to find an appropriate value of W/T.

4. Calculate the spread (T) by dividing the depressed section width (W) by the value of W/T from Step 3.

5. Find the spread above the depressed section (T_s) by subtracting W from the value of T obtained in Step 4.

6. Use the value of T_s from Step 5 along with Manning's n, S, and S_x to find the actual value of Q_s from Figure 3-3.

7. Compare the value of Q_s from Step 6 to the trial value from Step 1. If values are not comparable, select a new value of Q_s and return to Step 1.
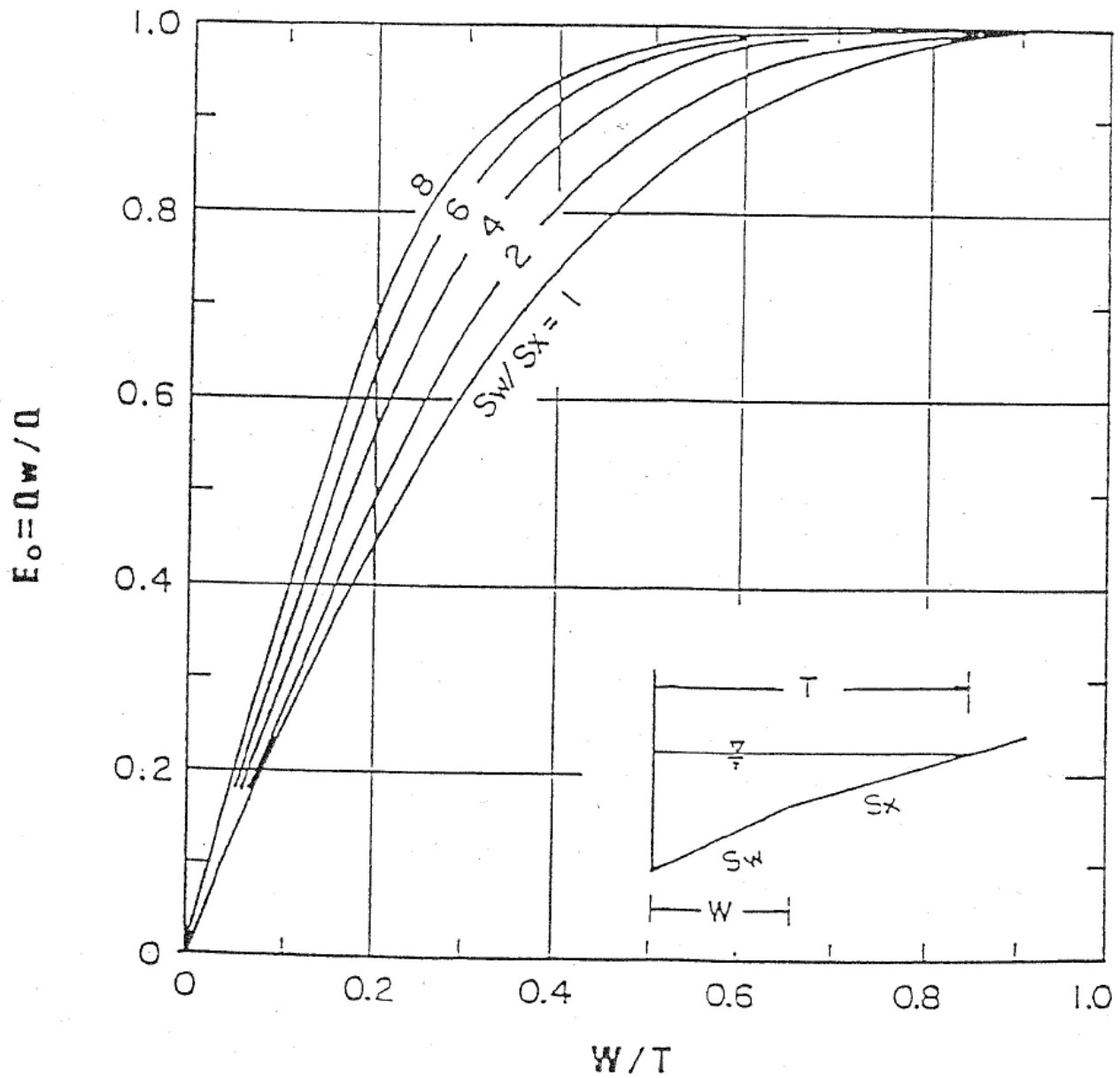
Figure 3-4 Ratio Of Frontal Flow To Total Gutter Flow

Source: AASHTO Model Drainage Manual, 1991

Condition 2: Find gutter flow, given spread.

1. Determine input parameters, including spread (T), spread above the depressed section (T_s), cross slope (S_x), longitudinal slope (S), depressed section slope (S_w), depressed section width (W), Manning's n, and depth of gutter flow (d).

2. Use Figure 3-2 to determine the capacity of the gutter section above the depressed section (Q_s). Use the procedure for uniform cross slopes (Condition 2), substituting T_s for T.

3. Calculate the ratios W/T and S_w/S_x, and, from Figure 3-4, find the appropriate value of E_o (the ratio of Q_w/Q).

4. Calculate the total gutter flow using the equation:

   Q = Q_s / (1 - E_o) (3.3)

   Where: Q = gutter flow rate (cfs)
   Q_s = flow capacity of the gutter section above the depressed section (cfs)
   E_o = ratio of frontal flow to total gutter flow (Q_w/Q)

5. Calculate the gutter flow in width (W), using Equation 3.2.

3.3.7   Examples

Example 1

Given: T = 8 ft
   S_x = 0.025 ft/ft
   S = 0.01 ft/ft
   n = 0.015

Find: (1) Flow in gutter at design spread
   (2) Flow in width (W = 2 ft) adjacent to the curb

Solution: (1)   From Figure 3-3, Qn = 0.03
   Q = Qn/n = 0.03/0.015 = 2.0 cfs

   (2) T_s = 8 - 2 = 6 ft
   $(Qn)_2$ = 0.014 (Figure 3-1) (flow in 6 ft width outside of width W)

   Q = 0.014/0.015 = 0.9 cfs

   Q_w = 2.0 - 0.9 = 1.1 cfs

Flow in the first 2 ft adjacent to the curb is 1.1 cfs and 0.9 cfs in the remainder of the gutter.

Example 2

Given: T = 6 ft S_w = 0.0833 ft/ft   n = 0.014
        T_s = 6 - 1.5 = 4.5 ft   S = 0.04 ft/ft
        S_x = 0.03 ft/ft   W = 1.5 ft

Find: Flow in the composite gutter

Solution: (1) Use Figure 3-3 to find the gutter section capacity above the depressed section.

Q_sn = 0.017

Q_s = 0.017/0.014 = 1.2 cfs

(2) Calculate W/T = 1.5/6 = 0.25 and

S_w/S_x = 0.0833/0.03 = 2.78

Use Figure 3-3 to find E_o = 0.64

(3) Calculate the gutter flow using Equation 3.3:

Q = 1.2/(1 - 0.64) = 3.3 cfs

(4) Calculate the gutter flow in width, W, using Equation 3.2:

Q_w = 3.3 - 1.2 = 2.1 cfs

3.4 Storm Water Inlets

3.4.1   Overview

The primary aim of drainage design is to limit the amount of water flowing along the gutters or ponding at the sags to quantities which will not interfere with the passage of traffic for the design frequency. This is accomplished by placing inlets at such points and at such intervals to intercept flows and control spread. In this section, guidelines are given for designing roadway features as they relate to gutter and inlet hydraulics and storm drain design. Procedures for performing gutter flow calculations are based on a modification of Manning's Equation. Inlet capacity calculations are based on information contained in HEC-12 (USDOT, FHWA, 1984). Storm drain design is based on the use of the rational formula.

Drainage inlets are located to limit the depth or spread on traffic lanes to allowable limits for the design storm. Grates should safely accommodate bicycle and pedestrian traffic where appropriate.

Inlets at vertical curve sags in the roadway grade should also be capable of limiting the spread to allowable limits. The width of water spread on the pavement should not be greater than the width of spread encountered on continuous grades. Inlets should be located so that concentrated flow and heavy sheet flow will not cross traffic lanes, and should be located just upgrade of pedestrian crossings and locations where the pavement slope reverses.

Inlets may be classified as being on a continuous grade or in a sump. The term "continuous grade" refers to an inlet located on the street with a continuous slope past the inlet with water entering from one direction. The "sump" condition exists when the inlet is located at a low point and water enters from both directions.

Inlets used for the drainage of paved or unpaved surfaces can be divided into two major classes. These classes are:

1. Grate Inlets - These inlets include grate inlets consisting of an opening covered by one or more grates, and slotted inlets consisting of a pipe cut along the longitudinal axis with a grate of spacer bar to form slot openings.

2. Curb-Opening Inlets - These inlets are vertical openings in the curb covered by a top slab.

3.4.2 Criteria

The following criteria shall be used for inlet design:

Land Use	Average Return Frequency (years)
Residential Areas	5
Commercial, Industrial, and Arterial Roads	10

Inlets
- 72-inch straight and canted inlets shall be used in the public street system
- Grate inlets may be used for parking lot drains, area drains, etc.
- Flow in the gutter should not exceed five (5) inches.
- Inlets should be placed at the low points in the street grade.

Design charts for standard City of Lincoln inlets are provided in the Chapter 3 of the Manual. The location of the first inlet shall be determined by a trial and error process based upon a point where the maximum depth of flow in the gutter is five inches. Subsequent inlets downstream from the initial inlets shall be located at or before points where the depth of flow in gutter is five inches. Usually inlets shall be placed at the ends of radii and/or before crosswalks at intersections. Inlets which the study shows are needed at locations other than at intersections shall generally be centered between lot lines. Inlets shall be installed at the upper end of all storm drain lines and at low points in the street grades. It may be necessary at some locations to use more than one inlet to pick up the contributing flow. Canted inlets Inlets shall not be placed along intersection radii, unless approved by the Director of Public Works and Utilities.

Concrete valley gutters may be used across roadways at T-intersections of local roadways, if the calculated depth of flow for the minor system design flow in the curb and gutter section immediately upstream is less than 5 inches and if there is no existing or proposed storm drain conduit extended to the intersection. The pavement cross-slope on the "uphill" lane of the minor approach shall be reduced at a gradual rate from 3% to 1% to allow drainage of the "uphill" gutter flow line through the return. No valley gutters shall be used across collector or arterial roadways.

Curb and gutter grades that are equal to pavement slopes shall not exceed 8 percent or fall below 0.5 percent without approval from the Director of Public Works and Utilities.

The detailed procedures and necessary charts to design inlets are described in Chapter 3 of the Manual. Curb and gutter installation shall be in accordance with the current Lincoln Standard Plans and Specifications.

3.4.3 Manholes

Manholes shall be installed at the upper end of all storm drain lines and at all changes in grade, size, or alignment. The recommended maximum spacing is 600 feet for storm drain lines, 36 inches and less in diameter. Greater spacings than this will require approval by the Director of Public Works and Utilities. The crowns of all storm drain pipes entering and leaving a junction shall be at the same elevation. Laterals from a storm drain inlet to the main storm drain line may be tapped directly into the main storm drain line if the diameter of the lateral does not exceed one-half the diameter of the pipe being tapped. If the diameter of the lateral does exceed one-half the diameter of the pipe being tapped, a storm drain manhole or inlet will be required. The crown of the lateral pipe shall match the crown of the main storm drain pipe. Storm drain manhole shall be constructed in accordance with the most current City Standard Drawings and Specifications.

3.4.4   Grate Inlets

A design chart for the three standard City of Lincoln grate inlets plus curb inlet in a sump condition is provided in Figure 3-5.

The capacity of an inlet depends upon its geometry and the cross slope, longitudinal slope, total flow, depth of flow and pavement roughness. The depth of water next to the curb is the major factor in the interception capacity of both gutter inlets and curb opening inlets. At low velocities, all of the water flowing in the section of gutter occupied by the grate, called frontal flow, is intercepted by grate inlets, and a small portion of the flow along the length of the grate, termed side flow, is intercepted. On steep slopes, only a portion of the frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. For grates less than 2 feet long, intercepted flow is small. Inlet interception capacity has been investigated by agencies and manufacturers of grates. For inlet efficiency data for various sizes and shapes of grates, refer to Hydraulic Engineering Circular No. 12 Federal Highway Administration and inlet grate capacity charts prepared by grate manufacturers.

3.4.5   Curb Inlets

Capacities for the standard City of Lincoln 72-inch straight and canted curb inlets are provided in Figures 3-6 and 3-7. Capacity of 48-inch straight inlets used for median drainage is provided in Figure 3-8. In extraordinary conditions, non-standard designs may be needed. Refer to "Drainage of Highway Pavements" Hydraulic Engineering Circular No. 12. A sample Inlet Design Computation Form is provided in Figure 3-9.

<u>Formulas for inlet capacities</u>

Inlet capacity in a sump is controlled by two flow conditions, weir flow and orifice flow. Figure 3-5 was developed using the following two equations:

Sump conditions

$$Q_w = 3.0 \ Pd^{1.5} \tag{3.4a}$$
and
$$Q_o = 0.67 \ A \ (2gd)^{0.5} \tag{3.4b}$$

Where, Q_w = weir capacity (cfs)   and, Q_o = orifice capacity (cfs)
         P   = perimeter (ft)   A = clear opening area (sf)
         d   = depth (ft)   g = acceleration of gravity - 32.2 ft/s^2
                                                                 d = depth (ft)

Curb inlet interception capacity is the flow intercepted by an inlet under a given set of conditions. The efficiency of an inlet changes with changes in cross slope, longitudinal slope, total gutter flow, and to a lesser extent, pavement roughness.

Curb inlets on grade formula
$$Q_i = Q_g \ (1 - (1 - E_L/kQ_g)^{0.42} \ s^{0.3} \ (1/ \ n \ S_e)^{1.8} \tag{3.5}$$

Where, Q_i = inlet capacity (cfs)
         Q_g= flow in the gutter (cfs)   s = pavement slope (ft/ft)
         E_L = effective length of inlet (ft)   n = Manning's roughness coefficient
         k   = 0.6 for US customary units S_e = composite slope of cross-section (ft/ft)

3.4.6   Flared End Sections

Capacities for flared end sections shall be determined using the procedures provided in Chapter 4 - Design of Culverts.
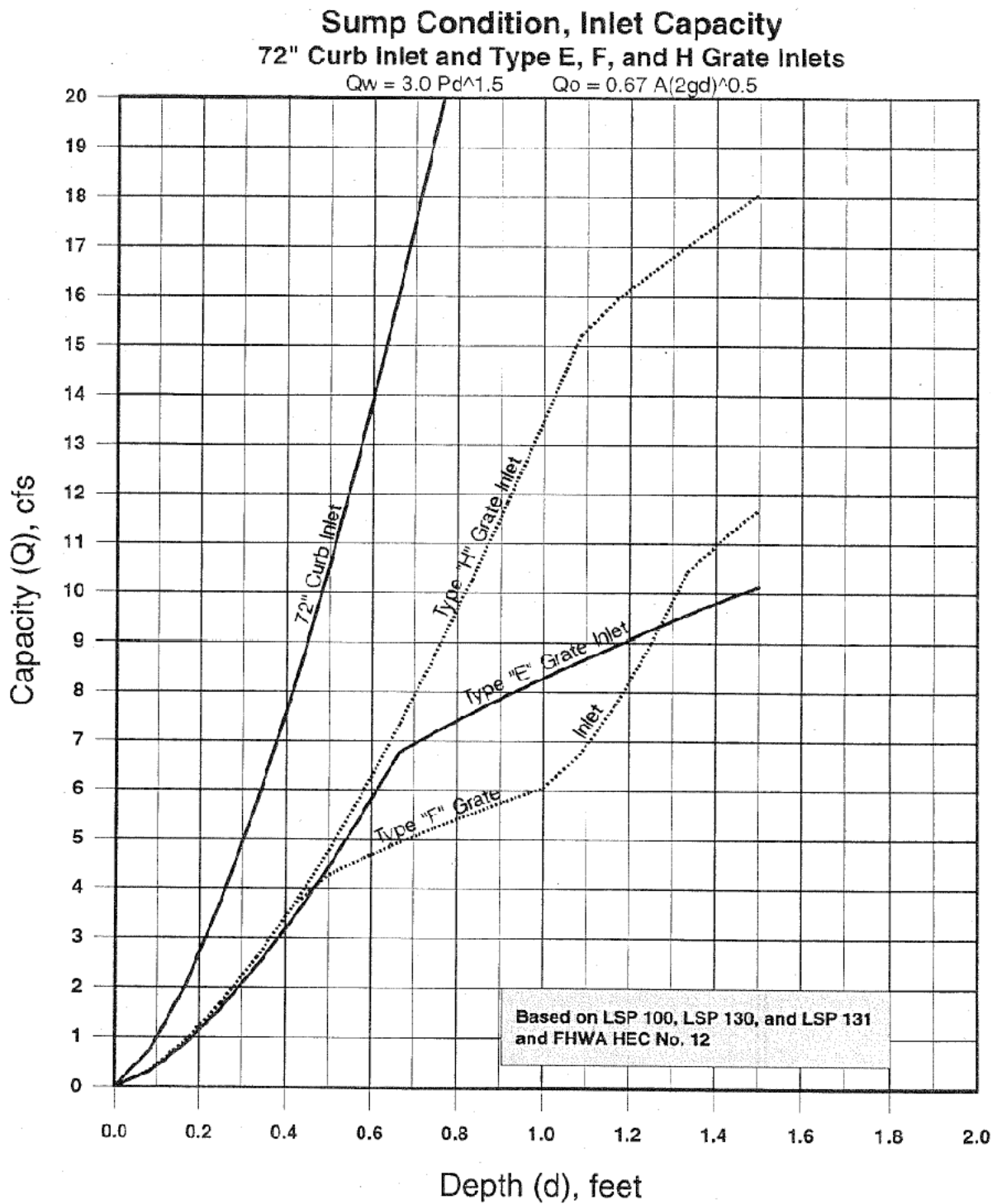
Sump Condition, Inlet Capacity
72" Curb Inlet and Type E, F, and H Grate Inlets
Qw = 3.0 Pd^1.5   Qo = 0.67 A(2gd)^0.5

Based on LSP 100, LSP 130, and LSP 131
and FHWA HEC No. 12

Figure 3-5 Capacity for City of Lincoln Standard Grate Inlets

Inlet Capacity
Standard 72-inch Straight Inlet

$$Qi = Qg (1- (1- 8/(KQg)^0.42 \, S^0.3 \, (1/(n \, Se))^1.8$$

Based on LSP 100 and FHWA HEC No.12
Effective Inlet Length of 8 feet

Gutter Flow (Qg), cfs

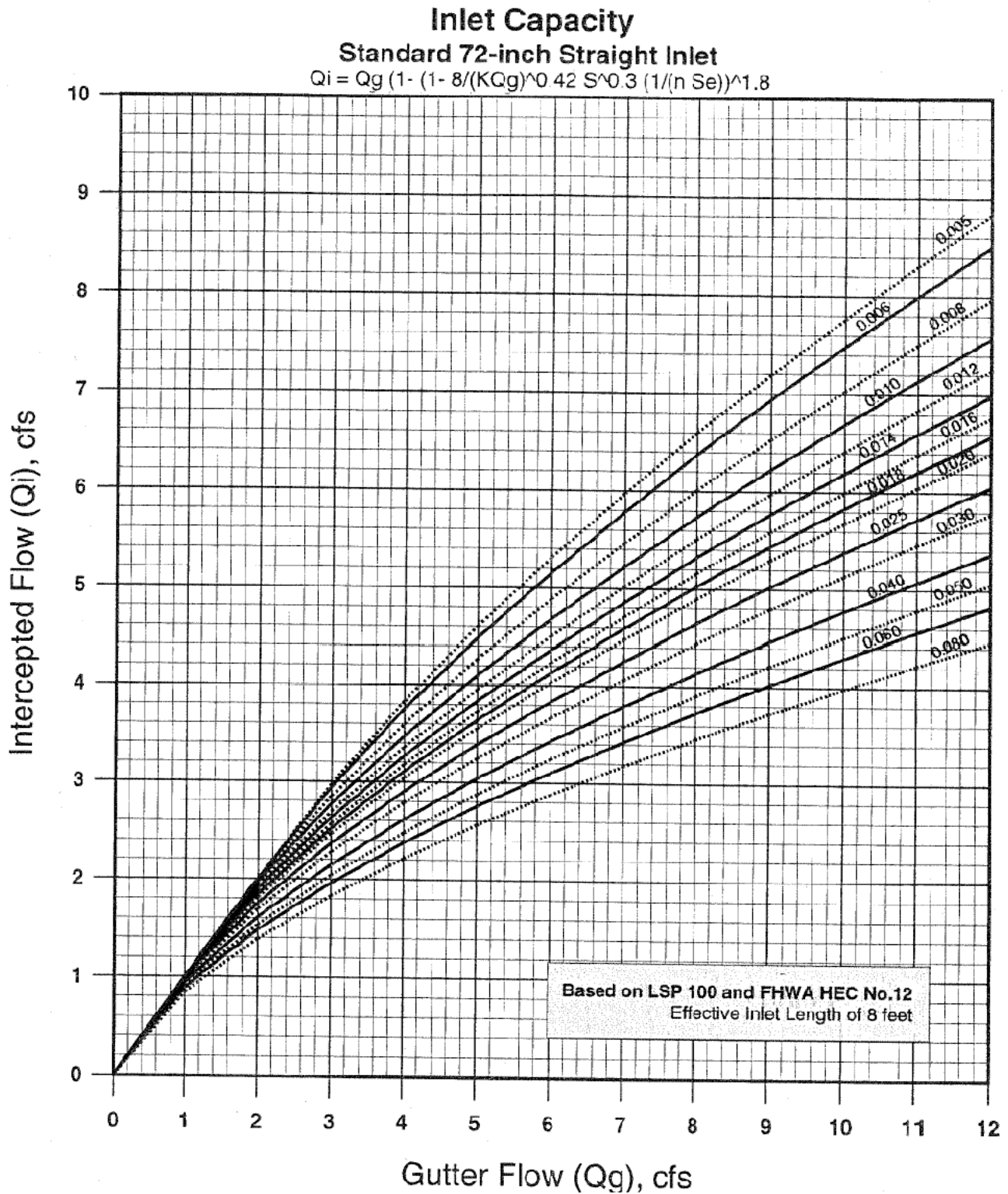**Figure 3-6 Inlet Capacity for City of Lincoln Standard 72-Inch
Standard Straight Curb Inlet**

Inlet Capacity
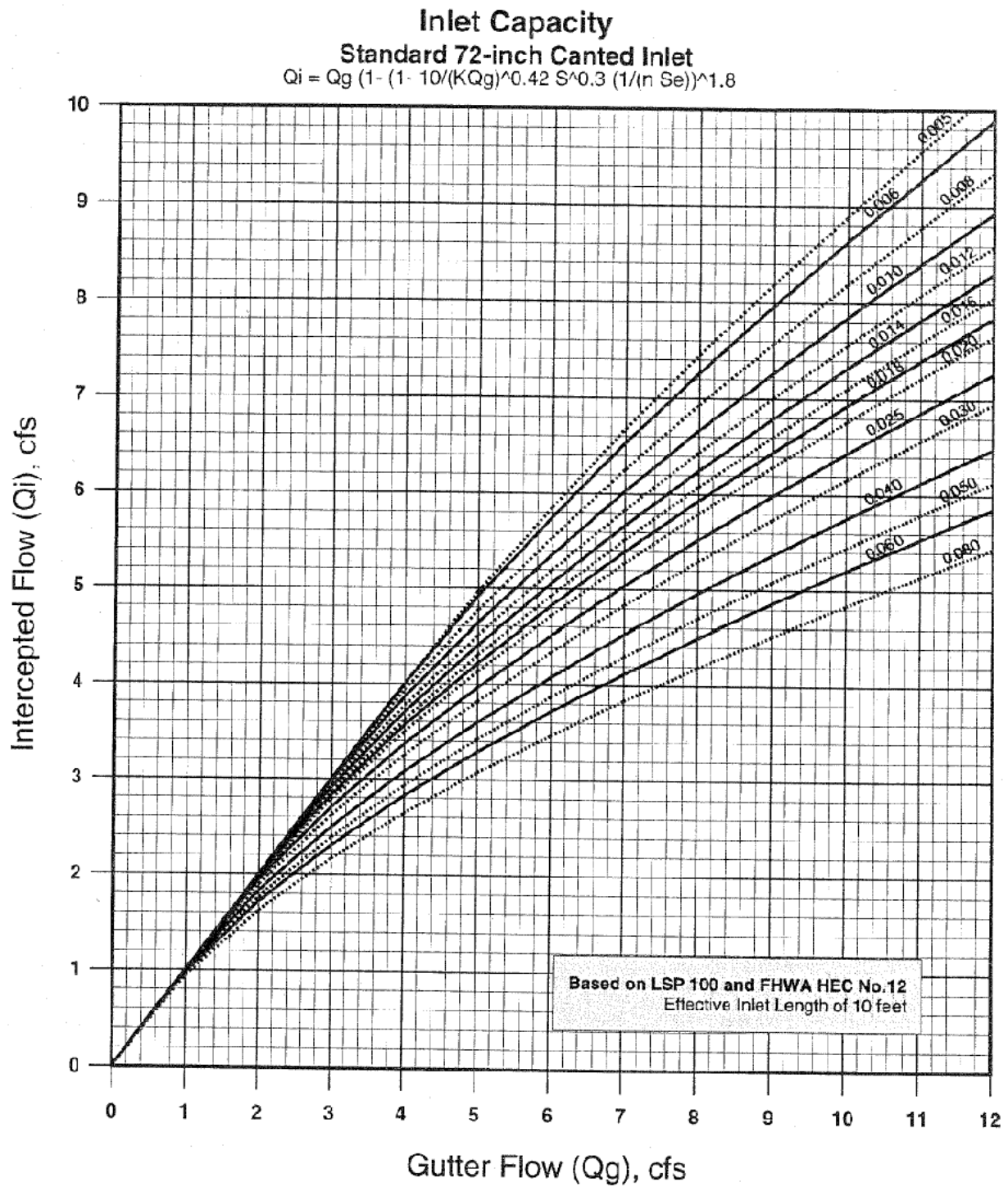**Standard 72-inch Canted Inlet**
Qi = Qg (1- (1- 10/(KQg)^0.42 S^0.3 (1/(n Se))^1.8

Figure 3-7 Inlet Capacity for City of Lincoln Standard 72-Inch
Canted Curb Inlet

Inlet Capacity
Standard 48-inch Straight Inlet

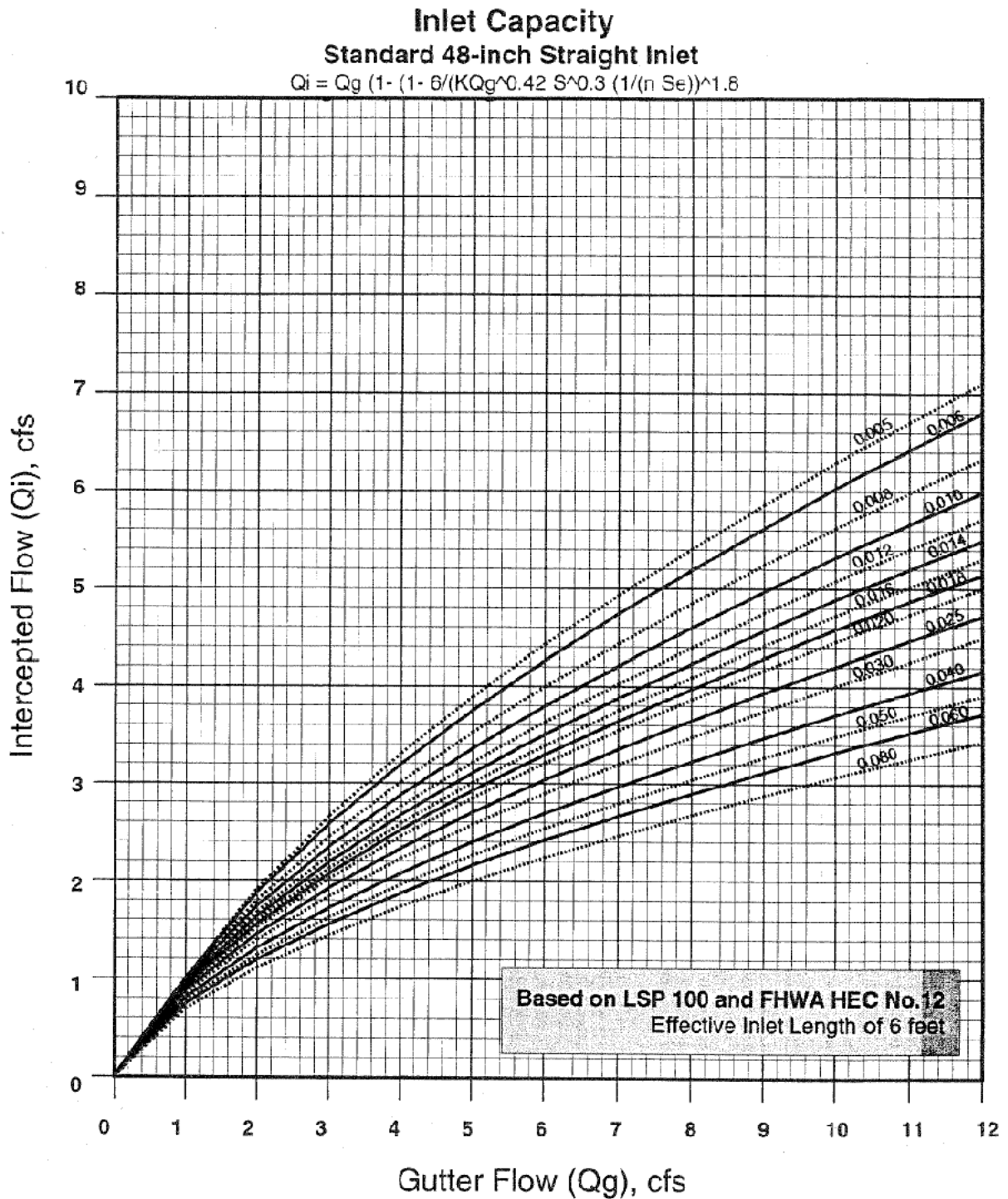$$Qi = Qg (1- (1- 6/(KQg^{0.42} S^{0.3} (1/(n Se)))^{1.8}$$

**Figure 3-8 Inlet Capacity for City of Lincoln Standard 48-Inch
Straight Curb Inlet**

Drainage Criteria Manual